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An Investigation into the Effects of Image Resolution on a Facial-Image-Based Personal Authentication System

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Abstract

The issues associated with image resolution in automated authentication or identification systems has become one of the important challenges for researchers' in biometrics. The aim of this thesis is to investigate the effect of variable resolutions on the performance of a Facial-Image-Based Person Authentication System. Image resolution may vary significantly especially in uncontrolled acquisition environments or when sensing from a distance and so on. The detail available in the data thus reduces which may deteriorate the performance of such system. In this project we investigated the impact on system accuracy when image resolution is gradually reduced by a given factor. As a remedy, we investigated different methods for increasing image resolution prior to using those images for authentication and compared the relative gains in accuracy. The main procedure of the face image authentication system based on comparing landmarks of the face remains the same.

In this study, we found that several issues related to image resolutions might have an impact on the recognition rate performance such as facial expressions, image background, and others. The influence of image resolution on the recognition rate increases roughly with the increasing resolution at a specific degree, high-image resolution would not be good for recognition rate always; reducing high image resolution makes it easier to achieve high face recognition rates.

CHAPTER 1: INTRODUCTION

1.1 Introduction

This chapter presents the background to the thesis, the research context and justification, clarifies terminology and presents an outline of the entire thesis.

1.2 Research Context and Justification

Face Recognition: the human face contains many individual characteristics that allow us to ascertain one face from another. Characteristics such as age, race and gender are combined with more specific attributes such as hair, nose, face shape, and mouth [2, 8] allow us to form opinions on a person's persona, and decisions on attractiveness. Every face has a number of distinguishable landmarks, the different peaks and valleys that make up facial features. Face recognition systems defines these landmarks as nodal points. Each human face has approximately 80 nodal points [2]. Some of these measured by the system are:

- Distance between the eyes
- Width of the nose
- Depth of the eye sockets
- The shape of the cheekbones
- The length of the jaw line

These nodal points can be measured, thus, creates a numerical code, called a Face-Print, to represent the faces [5].

Some facial recognition algorithms identify faces by extracting landmarks, or features, from an image of the subject's face. These features are then used to search for other images with matching features. Other algorithms normalize a gallery of face images and then compress the face data, only saving the data in the image that is useful for face detection [2]. A probe image is then compared with the face data. One of the earliest, successful systems is based on template matching techniques applied to a set of salient facial features, providing a sort of compressed face representation [2].

The logical process of the resolution on facial image-based recognition system is based on distinguishing features or photometric, which is a statistical approach that distill image into values and comparing the values with all images stored templates to eliminate variances [8].

1.3 Facial Recognition Systems

It is a computer application, which works on identifying or verifying a person in an authentication system. This system is based on the ability to recognize a face by measuring the various features of the face. Facial recognition system can pick someone's face out of a crowd, extract the face from the rest of the scene and compare it to a database of stored images based on image resolution [4]. The process of image matching usually involves three steps:

- Detection of the face in a complex background and localization of its exact position.

- Extraction of facial features such as eyes, nose, etc, followed by normalization to align the face with the stored face images.
- Face classification or matching [5].

In order for this system to work, it has to know how to differentiate between a basic face and the rest of the background. Background images have a distinctly different color composition than faces which influence on the image resolution. This nearly linear difference was exploited by creating a Fisher's Linear Discriminant (FLD) classifier to differentiate between average face colors and background colors [6]. The output of face detection is an image window containing only the face area. Irrelevant information, such as background, hair, neck and shoulders, ears, etc are discarded. This resulting face image-based resolution is one which further processed to extract a set of salient or discriminatory, local or global features, which will be used by the face classifier to identify or verify the identity of an unknown face [4].

In the past, facial recognition systems have relied on a 2D image to compare or identify another 2D image from the database, and so the image captured needed to be of a face that was looking almost directly at the camera, with little variance of light or facial expression from the image in the database, and this created a problem. A newly-emerging trend in facial recognition system uses a 3D model based resolution, which claims to provide more accuracy. Capturing a real-time 3D image a person's facial surface, 3D facial recognition uses distinctive features of the face, where rigid tissue and bone is most apparent, such as the curves of the eye socket, nose and chin, to identify the subject. These areas are all unique and do not change over time [7].

1.4 Research Trends in Face Recognition Study

The most popular research challenges in the Image-Based Face Recognition research area now are the following:

1.4.1 Recognition from Outdoor Facial Images

Recognition of face images acquired in an outdoor environment with changes in illumination and/or pose remains a largely unsolved problem; so in this research direction, many researches have been done to confront with many challenging problems, for example dealing with outdoor illumination, pose variation with large rotation angles, low image quality, low resolution, occlusion, and background changes in complex real-life scenes [9].

1.4.2 Recognition from Non-Frontal Facial Images

Non-frontal view facial recognition is important in many scenarios where the frontal views may be not available. Most of the existing methods of facial recognition are typically based on near frontal face data. Researches in this direction are concerned with the analysis of the non-frontal-view face images. With the accessibility of the recent 3D databases (ex: BU3DEF database [10]) researchers aim to benefit from the non-frontal facial images recognition to achieve equal or better performance than frontal view facial recognition [11].

1.4.3 Greater understanding of the Effects of Demographic Factors on Performance

Demographic factors are those relating to personal characteristics such as age, gender, family, level of education, social class, or race/ethnicity. Researches in this direction concerns with the relation between the demographic factors such as age and gender and the performance of face recognition [10].

1.5 Effect of Image Resolution

1.5.1 What is Image Resolution?

Resolution is defined as "the ability of an imaging system to record fine details in a distinguishable manner" [1]. A working knowledge of resolution is essential for understanding both practical and conceptual details of the images recognition process based on resolution. Along with the actual positioning of spectral bands, they are of paramount importance in determining the suitability of sensed data for a given applications. The major characteristics of imaging remote sensing instrument operating in the visible and infrared spectral region are described in terms as follow:

- Spectral Resolution.
- Radiometric Resolution.
- Spatial Resolution.
- Temporal Resolution [3].

1.5.2 Spectral Resolution

Refer to the width of the spectral bands, different parts of the face exhibit different spectral reflectance and emissivity. These spectral characteristics define the spectral position and spectral sensitivity. There is a tradeoff between spectral resolution and signal to noise. The use of well-chosen and sufficiently numerous spectral bands is a necessity [37].

1.5.3 Radiometric Resolution or Radiometric Sensitivity

Radiometric resolution technique determines how finely a system can represent or distinguish differences of intensity between images. Moreover, refer to the number of digital levels used to express the data collected by the sensor. It is commonly expressed as the number of bits (*Binary Digits*) needs to store the maximum level.

Here also there is a tradeoff between radiometric resolution and signal to noise. There is no point in having a step size less than the noise level in the data [24]. A low-quality instrument with a high noise level would necessarily, therefore, have a lower radiometric resolution compared with a high-quality, high signal-to-noise-ratio instrument. Also higher radiometric resolution may conflict with data storage and transmission rates.

1.5.4 Spatial Resolution

Spatial Resolution of an imaging system is defined through various criteria, the geometric properties of the imaging system, the ability to distinguish between point targets. Other methods of defining the spatial resolving power of a sensor are based on the ability of the device to distinguish between specified targets [15].

1.5.5 Temporal Resolution

Refers to the frequency with which images of a given geographic location can be acquired. Moreover, it refers to the precision of a measurement with respect to time. Often there is a tradeoff between temporal resolution of a measurement and its spatial resolution. This tradeoff can be attributed to the finite speed of light and the fact that it takes a certain period of time for the photons carrying information to reach the observer. In this time, the system might have undergone changes itself. Thus, the longer the light has to travel the lower is the temporal resolution [15].

1.6 Objectives of This Study

The aims during this study have been:

1. To investigate the current research ideas on facial-image-based authentication (Literature Review).
2. Obtaining findings and recommendations that may help researchers and developers to improve their work efficiency.

1.7 Thesis Outline

The remaining part of this thesis is organized as follows: chapter 2 contains the Literature Review, chapter 3 Background, chapter 4 contains Experiment Results of the Research Phase, and chapter 5 contains Conclusion and Future Work of the entire Study.

1.8 Summary

This chapter has given a general idea and background about the study. It has defined and justified the research context, as well as clarified terminologies used and outlined the rest of the thesis.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents the literature review which is recap the published important information..

2.2 Brief Description of classical Information Extraction System

In figure(2.1) shows the basic components comprising a typical general-purpose system used for digital Information Extraction [12].

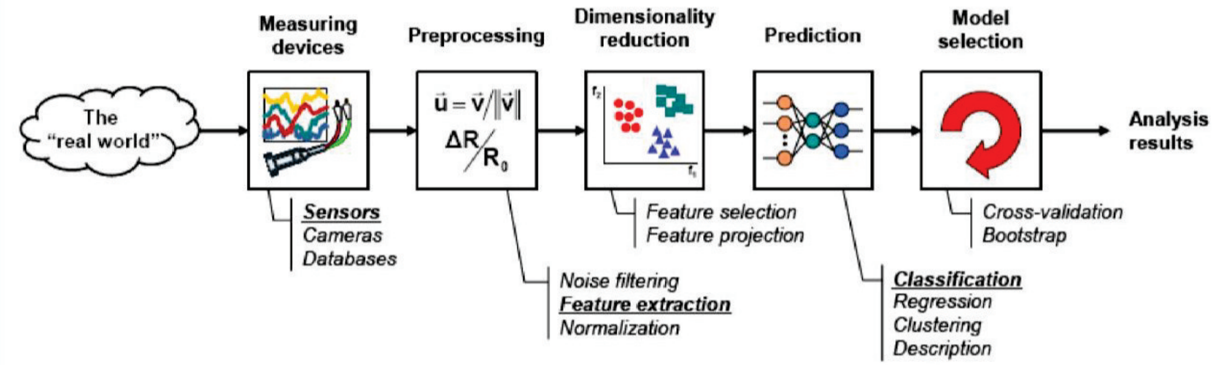


Figure2.1 Basic components of a typical general-purpose system used for digital information extraction.

Fundamental Steps include:

(1) **Low level processing**:
Inputs and outputs are images. Low level process involves primitive operations such as image processing to reduce noise, contrast enhancement and image sharpening.
Primitive operations are: digitization, enhancement, rotation, zooming, etc.

(2) **Med level processing**:
Mid level processes on image involves tasks such as segmentation, recognition.

Inputs are images, outputs are attributes extracted from images.
Primitive operations are: Segmentation, representation, and description.
(3) **High level processing**: Finally, higher level processing involves ―making sense‖ of an ensemble of recognized objects, as in image analysis and performing the cognitive functions normally associated with human vision.

Primitive operations include:[13]

(1) Image Enhancement:

Image enhancement is an important topic of digital image processing. Digital image enhancement techniques are concerned with the improvement of the quality of the digital image. Image enhancement is achieved by processing the image through operators.

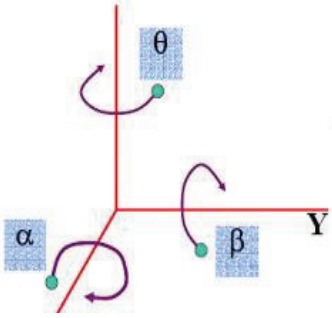
(2) Image Segmentation:

Segmentation is to subdivide an image into its constituent regions or objects. Segmentation should stop when the objects of interest in an application have been isolated.
Principal appraches:
Segmentation algorithms are based on one of two basis proberties of intesity values:

- Discontiuity: to partition an image based on abrupt changes in intensity (such as edges).
- Similarity: to partition an image into regions that are similar according to a set of predefined criteria.

(3) Image Rotation:

Rotation of a point about Z axis, by an angel θ (clockwise):



$$R_\theta = \begin{bmatrix} \cos\theta & \sin\theta & 0 & 0 \\ -\sin\theta & \cos\theta & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation of a point about X axis, by an angel α:

$$R_\alpha = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\alpha & \sin\alpha & 0 \\ 0 & -\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation of a point about Y axis, by an angel β:

$$R_\beta = \begin{bmatrix} \cos\beta & 0 & -\sin\beta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\beta & 0 & \cos\beta & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

(4) Image Digitalization:

The objective is to generate digital images from sensed data. The output of most of sensors is a continuous voltage waveform whose amplitude and spatial behavior are related to the physical phenomenon being sensed. To create a digital image, we need to convert the continuous sensed data into digital form. This involves two processes: sampling and quantization.

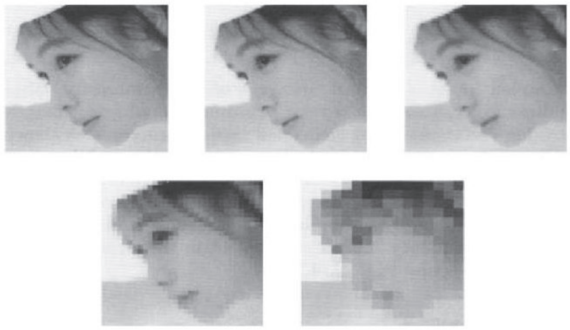


Figure2.2. Images sampled at 256*265, 128*128, 64*64, 32*32, and 16*16 rectangular sampling grids

2.3 Stages of Pattern Recognition

A pattern recognition investigation may consist of several stages, enumerated below. Not all stages may be present; some may be merged together so that the distinction between two operations may not be clear, even if both are carried out [14]:

1. Formulation of the problem: gaining a clear understanding of the aims of the investigation and planning the remaining stages.
2. Data collection: making measurements on appropriate variables and recording details of the data collection procedure (ground truth).
3. Initial examination of the data: checking the data, calculating summary statistics and producing plots in order to get a feel for the structure.
4. Feature selection or feature extraction: selecting variables from the measured set that are appropriate for the task. These new variables may be obtained by a linear or nonlinear transformation of the original set (feature extraction). To some extent, the division of feature extraction and classification is artificial.
5. Unsupervised pattern classification or clustering. This may be viewed as exploratory data analysis and it may provide a successful conclusion to a study. On the other hand, it may be a means of preprocessing the data for a supervised classification procedure.
6. Apply discrimination or regression procedures as appropriate. The classifier is designed using a training set of exemplar patterns.
7. Assessment of results. This may involve applying the trained classifier to an independent test set of labeled patterns.
8. Interpretation.

2.4 Biometric Authentication System

Figure(2.3) describes an access control system based on face authentication. In this model, each user has an account and a corresponding ID in the face database. On a user logging in the system, Face Authentication will use face recognition technologies to analyze and determine his ID as well as his permissions on the system.

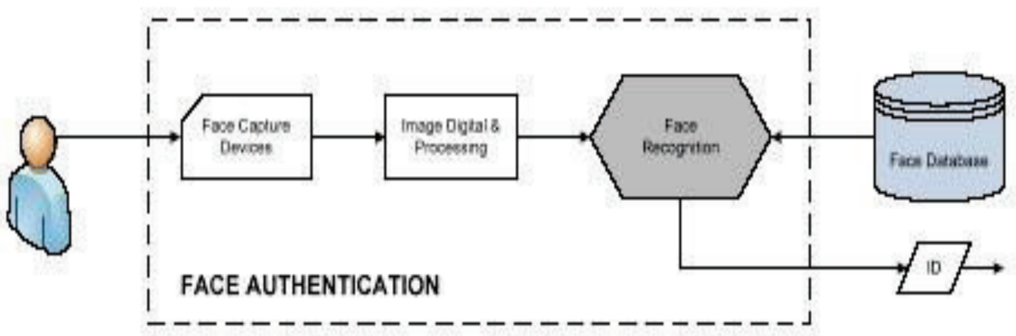


Figure2.3. Access Control System Based on Face Authentication Model

2.5 Factors Affecting the Performance of Face Recognition

Considerable progress has been made in face recognition research over the last Decade, especially with the development of powerful models of face appearance (e.g., eigen spaces). Despite the variety of approaches and tools studied, however, face recognition has shown to perform satisfactorily in controlled environments, but it is not accurate or robust enough to be deployed in uncontrolled environments. Several factors affect face recognition performance including pose variation, facial expression changes, face occlusion, and most importantly, illumination changes. Illumination variation is one of the critical factors affecting face recognition rate. Factors Affecting Face Imaging include the capture device physical properties properties (e.g. resolution and contrast).

2.6 Image Resolution Enhancement Techniques

Depending on the presence of anti-aliasing filer, there are two ways of formulating the resolution enhancement problem for still images, that is, how to obtain a highresolution (HR) image from its low-resolution (LR) version? When no anti-aliasing filter is used, we might use classical linear interpolation [16], edge-sensitive filter [17], directional interpolation [18], POCS-based interpolation [19], or edge directed interpolation schemes [20,21]. When anti-aliasing filter is involved, resolution enhancement is twisted with contrast enhancement by deploring which is an ill-posed problem itself [22]. When anti-aliasing filter takes the form of low-pass filter in wavelet transforms (WT) [23], there are a flurry of works [24–32] which transform the problem of resolution enhancement in the spatial domain to the problem of high- band extrapolation in the wavelet space. The apparent advantages of wavelet-based approaches include numerical stability and potential leverage into image coding applications (e.g., [33]). However, one tricky issue lies in the performance evaluation of resolution enhancement techniques—should we use subjective quality of highresolution (HR) images or objective fidelity such as mean-square errors (MSE)? The difficulty with the subjective option lies in that it opens the door to allow various contrast enhancement techniques as a post processing step after resolution enhancement. Both linear (e.g., [34]) and nonlinear (e.g., [35]) techniques have been proposed in the literature for sharpening reconstructed HR images. We note that *contrast* and *resolution* are two separate issues related to visual quality of still images. Tangling them together will only make the problem formulation less clean because it makes a fair comparison more difficult—that is, whether quality improvement comes from resolution enhancement or contrast enhancement? Therefore, we argue that subjective quality should not be used alone in the assessment of resolution enhancement schemes. Moreover, objective fidelity such as MSE can measure the closeness of computational approaches to the more costdemanding optics-based solutions, which is supplementary to subjective quality indexes. However, MSE-based performance comparison could be misleading if the role of anti-aliasing filter is not properly accounted. For example, in the presence of anti-aliasing filter, bilinear or bicubic interpolation would not be appropriate benchmark unless the knowledge of anti-aliasing filter is exploited by the reconstruction algorithm.

2.7 Super-resolution Imaging

Super-resolution is the process of recovering a high-resolution image from multiple low-resolution images of the same scene. An overview of existing super-resolution techniques includes the formulation of an observation model and coverage of the dominant algorithms: frequency domain methods, deterministic regularization, and stochastic techniques.[36,37,38].

Super-resolution, loosely speaking, is the process of recovering a high-resolution image from a set of low-resolution input images. Such algorithms have long been portrayed in movies and television; a typical movie scene showing a computer operator repeatedly zoom in on a person's face or a license plate where the missing high-resolution detail magically appears on the computer screen after each successive zoom. Clearly this is pure fiction, after all there are an infinite number of higher-resolution images that could form the original low-resolution image, right? With a single image and no *a priori* knowledge, this is true; however, higherresolution content *can* be recovered – to a point – if multiple low-resolution images are available of the same scene from slightly different poses. A closely related problem is that of *image restoration*, which utilizes *a priori* knowledge of the scene to recover missing detail from a *single* image1. So, while Hollywood almost always greatly exaggerates what can realistically be done, there actually is some merit to the ―zoom in and enhance‖ scenario commonly depicted.

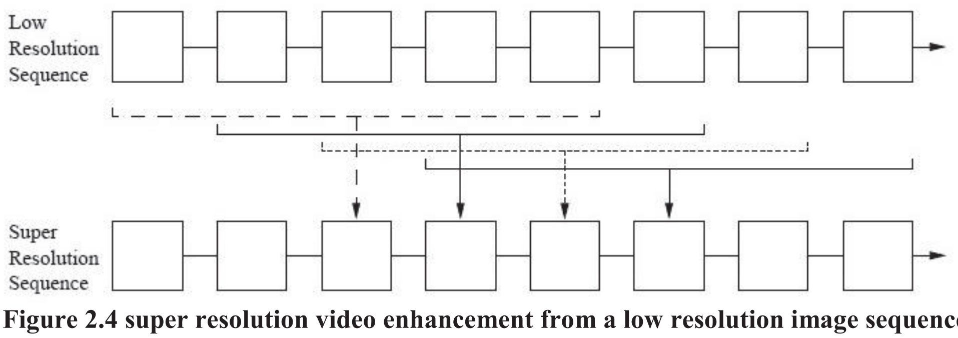


Figure 2.4 super resolution video enhancement from a low resolution image sequence .

CHAPTER 3: BACKGROUND

3.1 Introduction

This chapter presents the background to the thesis, which reviews the main methods and techniques that are used in thesis.

3.2 Face Recognition of Image-Based Resolution Method

Resolution is defined as "the ability of an imaging system to record fine details in a distinguishable manner" [1], face recognition systems may suffer if this resolution is deviated. In other words, Variable resolution is a source of inconvenience for such systems.

3.2.1 Face Recognition Systems

A facial recognition system is a computer application that automatically identifying or verifying a person from a digital image or a video frame from a video source. One of the ways to do this is by comparing selected facial features from the image and a facial database. It is typically used in security systems and can be compared to other biometrics such as fingerprint or iris recognition systems [7]. *Figure 3.1* illustrates the way of 2D facial scanner record identities through recognizing facial features.

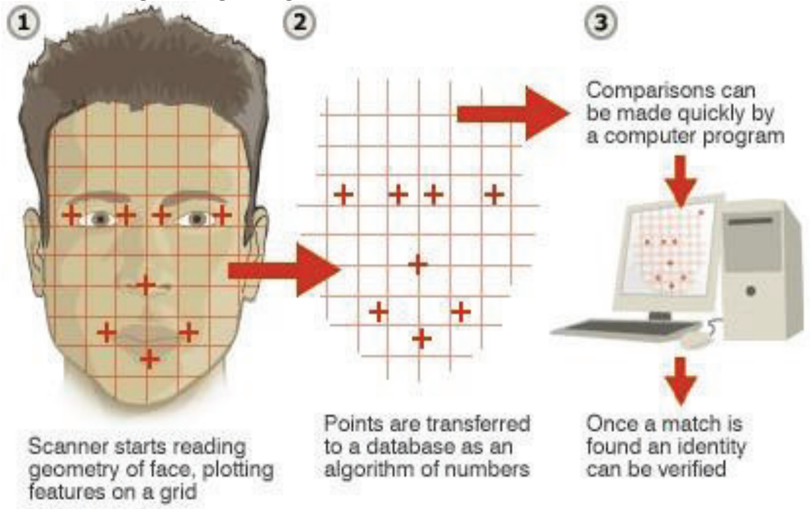


Figure 3.1: How 2D Facial Scanners Record Identities through Recognizing Facial Features.

There are also systems that look at faces holistically rather than looking at key features. Principal component analysis based eigenface approach is one good example of such approach.

3.2.2 Principal Component Analysis (PCA) Based Approach

It is a way of identifying patterns in data, and expressing the data in such a way as to highlight their similarities and differences. Since patterns in data can be hard to find in data of high dimension, where the luxury of graphical representation is not available, PCA is a powerful tool for analyzing data [39].

The other main advantage of PCA is that once it compresses the data, i.e. by reducing the number of dimensions, without much loss of information. This technique is used in image compression [39].

3.2.2.1 Properties of PCA

PCA is theoretically the optimal linear scheme, in terms of least mean square error, for compressing a set of high dimensional vectors into a set of lower dimensional vectors and then reconstructing the original set. It is a non-parametric analysis and the answer is unique and independent of any hypothesis about data probability. However, the latter two properties are regarded as weakness as well as strength, in that being non-parametric, no prior knowledge can be incorporated and that PCA compressions often incur loss of information [40]. Properties of PCA are classified into:

1- **Assumption on Linearity**

   We assumed the observed data set to be linear combinations of certain basis. Non-linear methods such as kernel PCA have been developed without assuming linearity [39] and [40].

2- **Assumption on the Statistical Importance of Mean and Covariance**

   PCA uses the eigenvectors of the covariance matrix and it only finds the independent axes of the data under the Gaussian Assumption (*See 3.3.1.4*). For non-Gaussian or multi-modal Gaussian data, PCA simply de-correlates the axes. When PCA is used for clustering, its main limitation is that it does not account for class reparability since it makes no use of the class label of the feature vector. There is no guarantee that the directions of maximum variance will contain good features for discrimination [40].

3- **Assumption of Large Variances that have Important Dynamics**

   PCA simply performs a coordinate rotation that aligns the transformed axes with the directions of maximum variance. It is only when we believe that the observed data has a high signal-to-noise ratio that the principal components with larger variance correspond to interesting dynamics and lower ones correspond to noise [40].

3.2.3 Face Recognition System Using PCA Technique

The Principal Component Analysis (PCA) is one of the most successful techniques that have been used in image recognition and compression. Moreover, PCA is a statistical method under the broad title of factor analysis. The purpose of PCA is to reduce the large dimensionality of the data space (observed variables) to the smaller intrinsic dimensionality of feature space (independent variables), which are needed to describe the data economically [39]. This is the case when there is a strong correlation between observed variables. The tasks which PCA can do are prediction, redundancy removal, feature extraction, data compression, and etc. *Figure 3.2* illustrates the phases of PCA technique used in Face Recognition System.

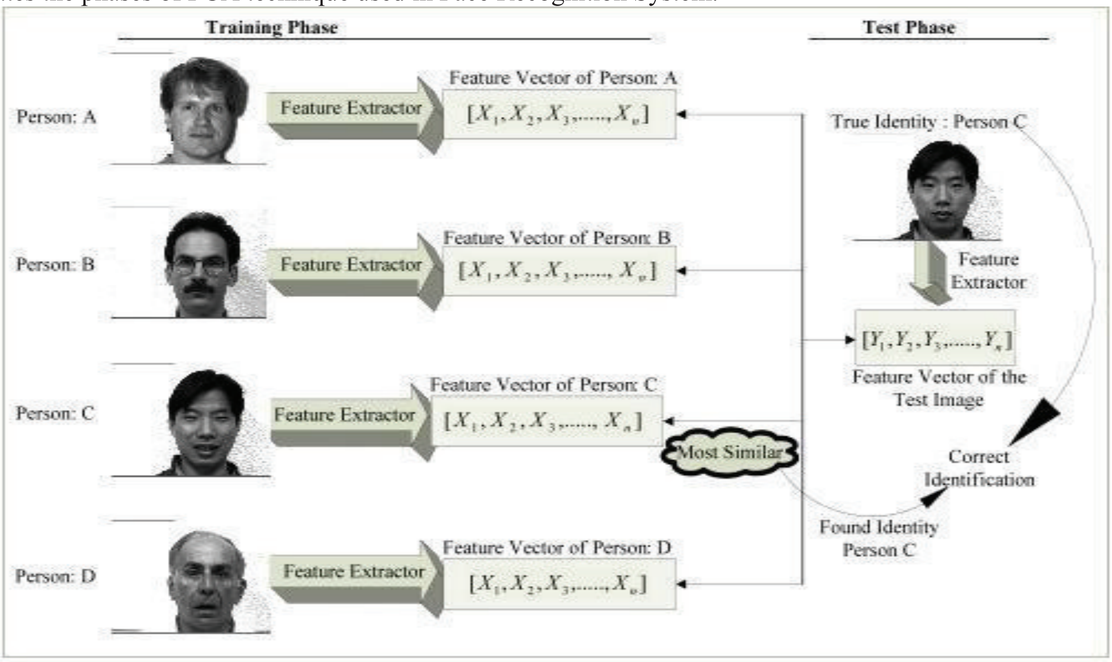


Figure 3.2: The Phases of PCA Technique used in Face Recognition System.

3.2.3.1 The Phases of PCA Technique used in Face Recognition System

1. **The Training Phase**

   In this phase, the features' vectors for each facial image in the training set will be extracted.

   A- Given a training set $\mathbf{t_1, t_2, ..., t_N}$ of **N** facial images such that
   - Each image is n by m pixels.
   - All images have the same size.

   B- Computing the PCA representation, where each image is interpreted as a point in $\mathbf{R}^{n \times m}$ (Face Space)
   - The PCA representation is characterized by a set of **N-1** Eigen-vectors (**e1**, **e2**, ….., **eN-1**) and Eigen-values (**λ1**, **λ2**, ….., **λN-1**).
   - The eigenvectors referred to as Eigen-faces.

2. **The Testing Phase (Recognition Phase)**

   In this phase, the feature vector of the test image compared with features vectors of all images in the training set to get the equivalent image.

   A. Given a test image, **x**, of a known person (included in the training set).
   B. Compute the feature vector of this person using PCA, **ω**
   C. Compute the similarities between the feature vector **ω** and all of the features vectors $\mathbf{e_i}$ in the training set. The similarities between features vectors can be computed using Euclidean Distance.
   D. Choose the most similar $\mathbf{e_i}$ (the minimum distance between **ω** and $\mathbf{e_i}$), and using the index **i** to recognize the matched image in the training set [39].

3.2.3.2 Main Idea of Using PCA for Face Recognition

To express the large 1-D vector of pixels constructed from 2-D facial image into the compact principal components of the feature space. This can be called Eigen-space projection. Eigenspace is calculated by identifying the Eigen-vectors **u** by solving $\mathbf{Cu = \lambda u}$ of the covariance matrix $\mathbf{C = \phi\phi^t}$ derived from a set of facial images (Vectors) [40].

3.3 Face Image Resolution Analysis Methods

3.3.1 Image Scaling and Resizing

Image scaling and resizing is the process of resizing a digital image. Scaling is a non-trivial process that involves a trade-off between efficiency, smoothness and sharpness. As the size of an image is increased, so the pixels which comprise the image become increasingly visible, making the image appears "soft" [41].

Conversely, reducing an image will tend to enhance its smoothness and apparent sharpness. Enlarging an image is used for "Zooming" an image, it is not possible to discover any more information in the image than already exists, and image quality inevitably suffers. However, there are several methods of increasing the number of pixels that an image contains, which evens out the appearance of the original pixels.

3.3.1.1 Interpolation

Image interpolation occurs in all digital photos at some stage, whether this is in BayerDemosaicing or in photo enlargement. It occurs anytime you resize or remap (Distort) your image from one pixel grid to another.

Image resizing is necessary when you need to increase or decrease the total number of pixels, whereas remapping can occur under a wider variety of scenarios: correcting for lens distortion, changing perspective, and rotating an image [41].

Even if the same image is resized or remapped, the results can vary significantly depending on the interpolation algorithm. It is only an approximation; therefore an image will always lose some quality each time interpolation is performed.

In summary, Interpolation is a technique that pervades many an application. Interpolation is almost never the goal in itself, yet it affects both the desired results and the ways to obtain them. Furthermore, interpolation is the process of determining the values of a function at positions lying between its samples. It achieves this process by fitting a continuous function through the discrete input samples. This permits input values to be evaluated at arbitrary positions in the input, not just those defined at the sample points [42].

The goal of image interpolation is to produce an image ***u*** at a different resolution $\delta x' \times \delta y'$. For simplicity, we will assume that the Euclidean coordinates are scaled. By the same factor K

$$U(x, y) = C_{\underline{\delta x}, \underline{\partial y}}(x, y)\ f(x, y), \qquad (x, y) \in \Omega.$$

K K

Figure 3.3: Illustration of the Interpolation Process, Resizing Original Image (Left) to Interpolated Image (Right).

3.3.1.2 Interpolation Algorithms

Common interpolation algorithms can be grouped into two categories: adaptive and nonadaptive. Adaptive methods change depending on what they are interpolating (sharp edges vs. smooth texture), whereas non-adaptive methods treat all pixels equally.

1. **Non-Adaptive Algorithms:** include Nearest Neighbor, Bilinear, Bicubic, Spline, Sinc, Lanczos and others. Depending on their complexity, these use anywhere from 0 to 256 (or more) adjacent pixels when interpolating. The more adjacent pixels they include, the more accurate they can become, but this comes at the expense of much longer processing time. These algorithms can be used to both distort and resize a photo [42].

2. **Adaptive Algorithms**: include many proprietary algorithms in licensed software such as: Qimage, PhotoZoom Pro, Genuine Fractals and others. Many of these apply a different version of their algorithm (on a pixel-by-pixel basis) when they detect the presence of an edge, aiming to minimize unsightly interpolation artifacts in regions where they are most apparent. These algorithms are primarily designed to maximize artifact-free detail in enlarged photos, so some cannot be used to distort or rotate an image [42].

3.3.1.3 Types of Non-Adaptive Interpolation Algorithms

1. nearest Neighbor Interpolation

It's clear that nearest neighbor is the most basic and requires the least processing time of all the interpolation algorithms. It is such easy because it only considers one pixel- the closest one to the interpolated point. This has the effect of simply making each pixel bigger [42].

2. Bilinear Interpolation

Bilinear interpolation is the second easy and efficient interpolation algorithm. It considers the closest 2x2 neighborhood of known pixel values surrounding the unknown pixel. It then takes a weighted average of these 4 pixels to arrive at its final interpolated value. This results in much smoother looking images than nearest neighbor.

Figure 3.4 shows a diagram case when all known pixel distances are equal, so the interpolated value is simply their sum divided by four [42].

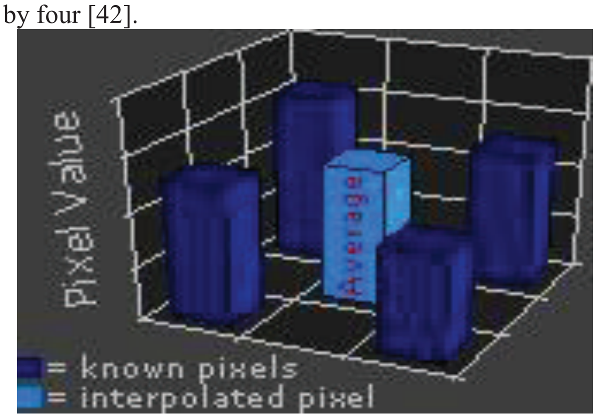


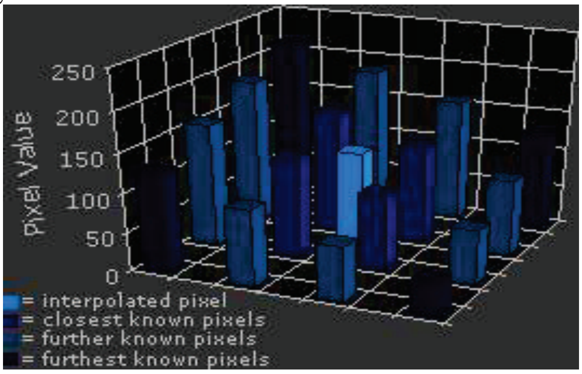
Figure 3.4: Bilinear Interpolation.

3. Bicubic Interpolation

Bicubic goes one step beyond bilinear by considering the closest 4x4 neighborhood of known pixels, for a total of 16 pixels. Since these are at various distances from the unknown pixel, closer pixels are given a higher weighting in the calculation.

Bicubic produces noticeably sharper images than the previous two methods, and is perhaps the ideal combination of processing time and output quality. For this reason it is a standard in many image editing programs (including Adobe Photoshop), printer drivers and in-camera interpolation [42].

Figure 3.5 shows a diagram case when all known pixel distances are equal, so the interpolated value is simply their sum divided by sixteen.



Moreover, a sample of two set of images were obtained from the ORL-Face Database that elaborate the differences between the original images and electronically modified images which have been correctly identified prior interpolation process (Input Image) in figure 3.6 below as well as the bicubic interpolated images (4x4).

(A) (B) (C)

Figure 3.6: where (A) Original Image, (B) Input Image, and (C) Bicubic Interpolation.

3.3.1.4 Gaussian Pyramid

A Gaussian Pyramid is a technique used in image processing, especially in texture synthesis.

The technique involves creating a series of images which are weighted down using a Gaussian average (Gaussian Blur) and scaled down [43]. *Figure 3.7* shows the levels of Gaussian Pyramid.

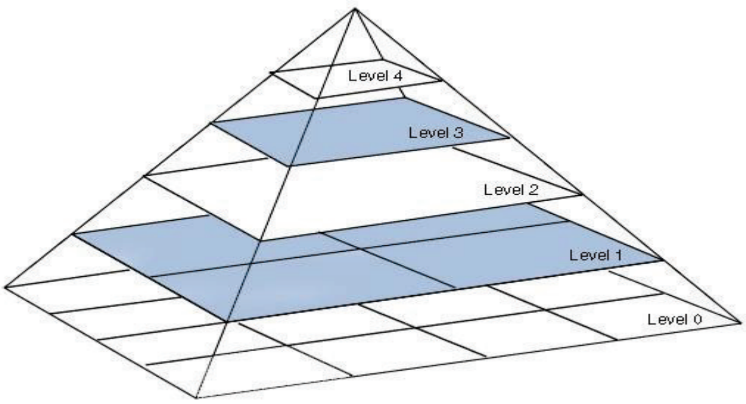


Figure 3.7: Levels of Gaussian Pyramid.

When this technique is used multiple times**Figure 3.5: Bicubic Interpolation.**
, it creates a stack of successively smaller images, with each pixel containing a local average that corresponds to a pixel neighborhood on a lower level of the pyramid.

Let $I(x,y)$ be the original image, The Gaussian pyramid is defined as:

$$G_0(x,y) = I$$

$$G_{i+1}(x,y) = REDUCE(G_i(x,y))$$

The REDUCE operation is carried out by convolving the image with a Gaussian low pass filter [44].

The Generalized Gaussian Pyramid is essential technique for Face Image Information Analysis, when observing an image, people will usually see it more clearly when moving nearer and see it most clearly when the distance is (smaller than) one fixed value d0. If the image is known to be a face, we will recognize it when the distance is another fixed value d1, which is usually larger than d0 [1].

Figure 3.7: Lowering Resolution Face Images Using the Gaussian Pyramid

3.3.2 Super Resolution

Super-Resolution (SR) is technique that enhances the resolution of an imaging system. Some SR techniques break the diffraction-limit of systems, while other SR techniques improve over the resolution of digital imaging sensor. There are two variants of super resolution technique which are: single-frame and multiple-frame variants of SR [45][48].

The performance of existing face recognition systems decreases significantly if the resolution of the face image falls below a certain level. Therefore, the logical application of super-resolution technique for face recognition system can be elaborated in the following figures 3.8 and 3.9 based on super-resolution reconstruction and feature vector extraction.

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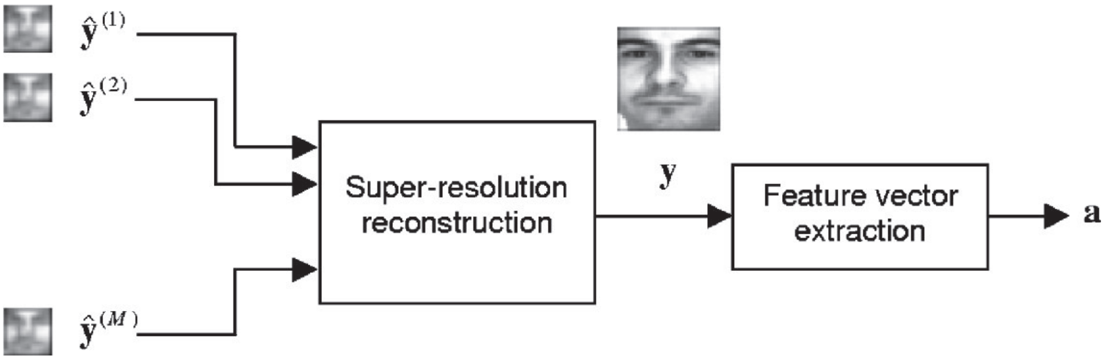

Figure 3.8: The Applied Pre-Processing Method of Super-Resolution Technique Applied to Face Recognition.

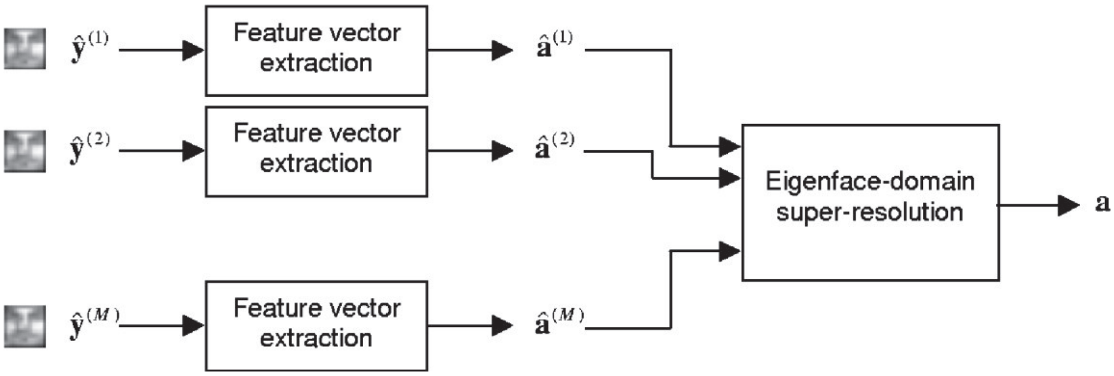

Figure 3.9: Super-Resolution Embedded Into Eigenface-Based Face Recognition.

3.3.2.1 Variants of Super Resolution

1. **Multiple-Frame Super Resolution**
   It uses the sub-pixel shifts between multiple low resolution images of the same scene. They create an improved resolution image fusing information from all low resolution images, and the created higher resolution images are better descriptions of the scene [45].
2. **Single-Frame Super Resolution**
   It uses methods attempt to magnify the image without introducing blur. These methods use other parts of the low resolution images, or other unrelated images, to guess what the high resolution image should look like.
   In summary, algorithms can also be divided by their domain: frequency or space domain. Originally super-resolution methods worked well only on grayscale images, but researchers have found methods to adapt them to color camera images. Recently also the use of superresolution for 3D data has been shown [45].

3.4 Summary

This chapter described a number of underlying techniques for face recognition and image scaling some of which will be used in the empirical studies of this project.

CHAPTER 4: EXPERIMENTAL RESULTS

4.1 Introduction

The aim of the experiment process is to find out the relation curve between face recognition performances and face image-based resolution. In this experiment, I randomly choose a set of images for each subject as the testing part and the remainders as the training part from two databases (ORL-Face, and Yale-Face B Databases). I test PCA face recognition method with Bicubic Interpolation, Nearest Neighbor Interpolation, and Gaussian Pyramid. The result is depicted in Figures 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, and 4.12. From the curve changing trend, we can observe that the influence of image resolution on the recognition rate, which increases roughly with the increasing resolution.

4.2 Facial Images Sample

The experiments conducted in this study used two popular publicly available face databases: ORL face database and Yale face database. The following two subsections give the details of these two databases. There is a well-known face database which can be downloadable from the AT&T Laboratories, Cambridge at http://www.uk.research.att.com/facedatabase.html .

4.2.1 ORL-Face Database

ORL-Face Database contains ten different images of each of 40 distinct subjects. Furthermore, the images used in this experiments are shown in 4.1, 4.2, 4.3, and 4.4, the images were taken at different times, varying the lighting, facial expressions (open/closed eyes, smiling/not smiling) and facial details (glasses/no glasses). All the images were taken against a dark homogeneous background with the subjects in an upright, frontal position (with tolerance for some side movement).

The database contains a set of faces taken between April 1992 and April 1994 at the Olivetti Research Laboratory in Cambridge, UK.

There are:

- 10 different images of 40 distinct subjects.
- For some of the subjects, the images were taken at different times, varying lighting slightly, and facial expressions: (Open/closed eyes, smiling/non-smiling) and facial details (glasses/no-glasses).

All the images are taken against a dark homogeneous background and the subjects are in upright, frontal position (with tolerance for some side movement). The size of each image is 92 x 112; 8-bit grey levels, these images are varying from different gender, age, and race [47]. *Figure 4.1 and 4.2* show two different samples of ORL database.

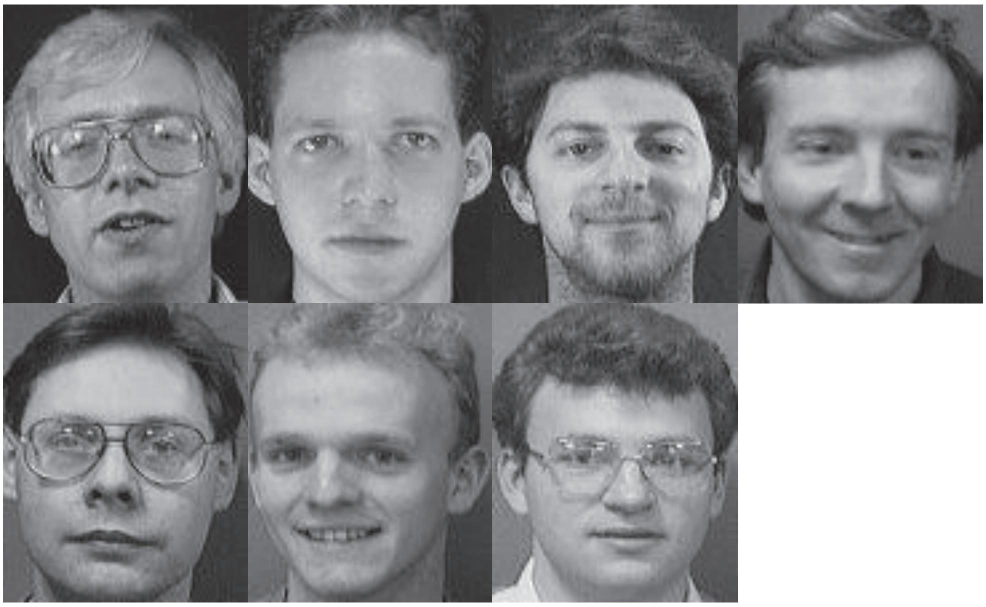

Figure 4.1 Sample of ORL-Face Database

Figure 4.2 ORL-Face Database Sample of Different Images for three Subjects

4.2.2 Yale-Face Database B

The Yale-Face database contains:

- 165 grayscale images in GIF format of 15 individuals.
- There are 11 images per subject, one per different facial expression or configuration: center-light, w/glasses, happy, left-light, w/no glasses, normal, rightlight, sad, sleepy, surprised, and wink. Figures 4.3 and 4.4 show two different samples of Yale-Database [49].

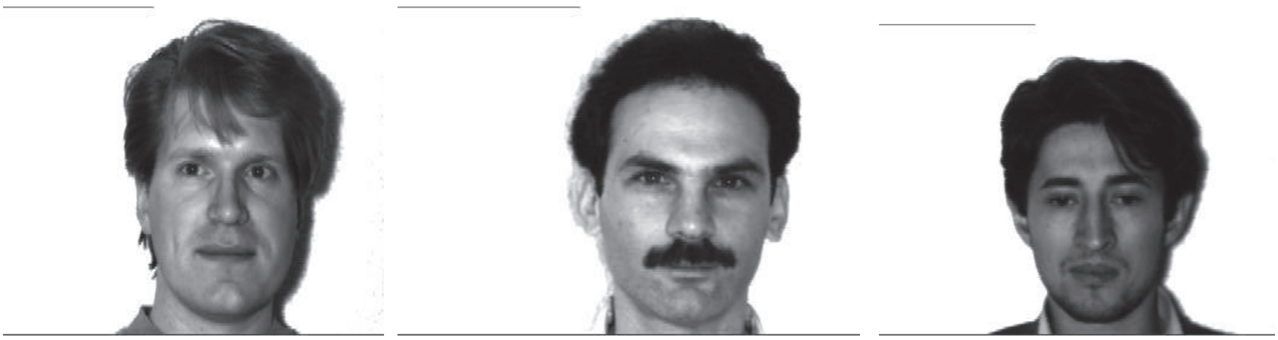

Figure 4.3 Sample of Yale database

Figure 4.4 Yale-Database Sample of different facial expression

4.3 Experimental Setup Methodology

An experiment with a subset of the two databases, which contain subject images, has been performed to ensure how well the Eigen-Face system can identify each individual's face. Please note that this experiment is not exhaustive for the databases. The experiment has been implemented in MATLAB. Some subjects are selected as training set and other subjects are the part of test set, which should be classified as unknown faces.

The two data sets used for the study are pre-processed through a set of procedures that can be explained in *figure 4.5* below.

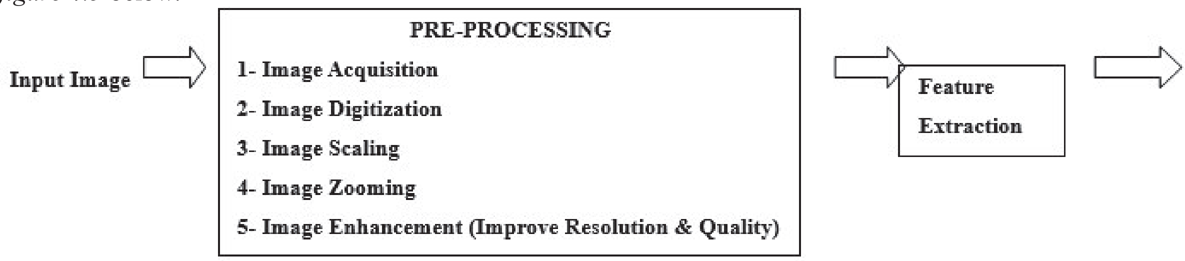

Figure 4.5: The Experiments Methodology Used.

The above mentioned pre-processes are used in the experimental results. Image Zooming pre-process, the optically zoomed image set with the same inter-ocular distance as the SR processed image, the combination of SR and wavelet Lasso achieves comparable recognition rates as the optically zoomed probe, which demonstrates the feasibility and effectiveness of using a purely software based approach to increase face resolution and recognition rates. Image Scale pre-process, a scale pre-processing based on wavelet transforms is used and proves to be effective in restoring and enhancing data with high magnification values. In pre-process for quality, the outdoor images were chosen in the study for the degradations in face recognition rates introduced by an increased system magnification and observation distance. Apart from illumination, pose, and expression, magnification blur is identified as another major deteriorating source for long range data. To describe the corresponding degradations, an adaptive face image quality measure is developed based on image sharpness measures.

4.4 The Principal Component Analysis (PCA)

The Eigen-Face algorithm uses the Principal Component Analysis (PCA) for dimensionality reduction to find the vectors which best account for the distribution of face images resolution within the entire image space.

The experimental results presented in the experiment results section are obtained using the ORL-Face and Yale-Face Database. In this experiment, I tested PCA face recognition method with:

- Gaussian Pyramid,
- Nearest Neighbor Interpolation - Bicubic interpolation Classifiers.

4.5 Experiment Results

1. The followings are the experiment results which show the effect of resolution on recognition performance, image samples are obtained from ORL-Face Database; the algorithms have been implemented using MATLAB. Images are selected randomly based on different facial expressions, gender, race, and distance; 90 samples of ORL-Face database and 100 samples of Yale-Face Database B were selected randomly to train the system. 140 samples were used randomly as test images for testing, and 28 images for training.

Reduction Factor: is the process of reducing the high resolution of selected face images to check the recognition rate for a specific set of images using three PCA face recognition methods, Gaussian Pyramids, Bicunic Interpolation, and Nearest Neighbor Interpolation.

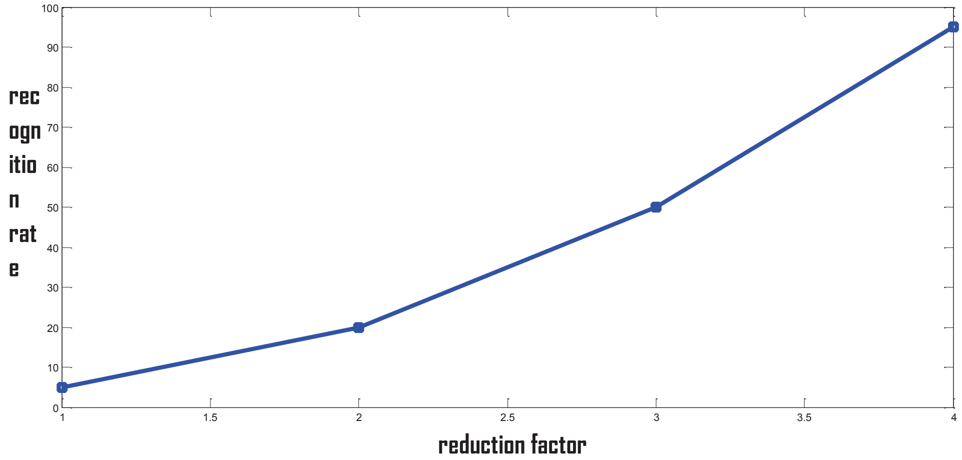

Figure 4.6 Results of ORL Face Database using Gaussian Pyramid

Experimental results show that the reduction factor achieves a significant improvement in recognition rate with high dimensionality reduction of the resolution vector as compared with the other methods used below. Reducing high image resolution makes it easier to achieve high face recognition rates.

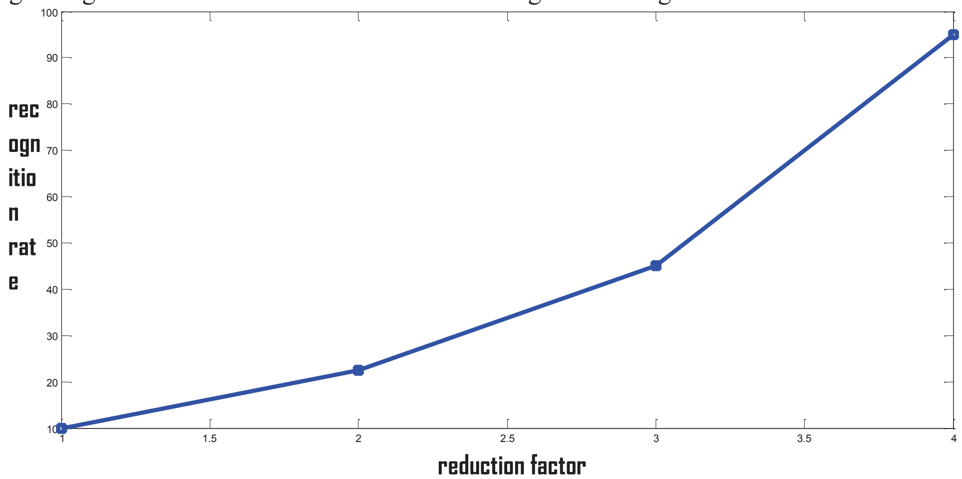

Figure 4.7 Using Bicubic Interpolation Algorithm on ORL-Face Database

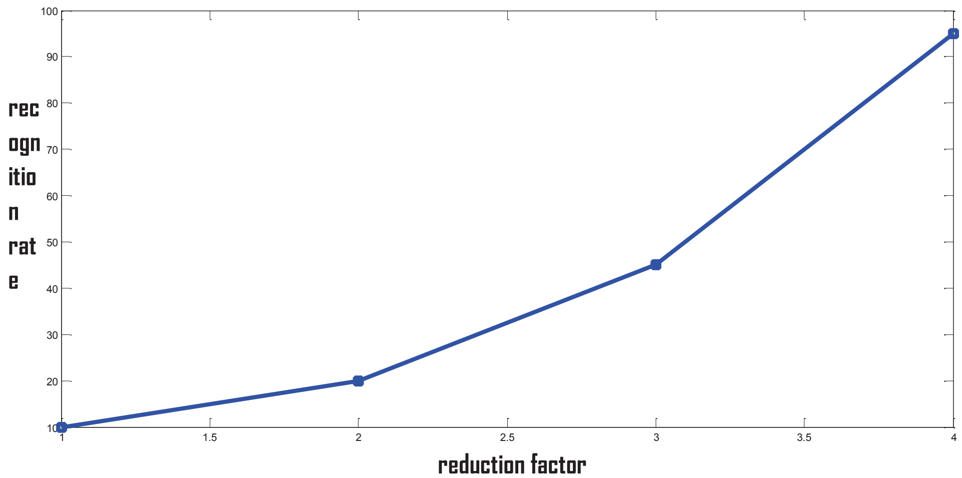

Figure 4.8 Using Nearest Neighbor Interpolation Algorithm on ORL-Face Database

The result is depicted in Figures 4.6, 4.7, and 4.8 from the curve changing trend, we can observe that the threshold recognition rate is increases roughly (radical improvement) with the increasing of reduction factor, the rate keeps stable when the high resolution reducing.

2. The followings are the experiment results which show the effect of resolution on recognition performance, image samples are obtained from Yale-Face Database; the results have been implemented using MATLAB.

The recognition rate of Yale-Face Database is just 40% which more likely similar to what other researchers have found, because there are many things affect it. For example, YaleFace Database has a big white background as well as the size of the face is small (the images have to be processed for more accurate results by cropping the faces for excluding the background, Image cropping pre-process was not used in my experiments setup methodology) this factor will be effective on the resolution performance of recognition rate.

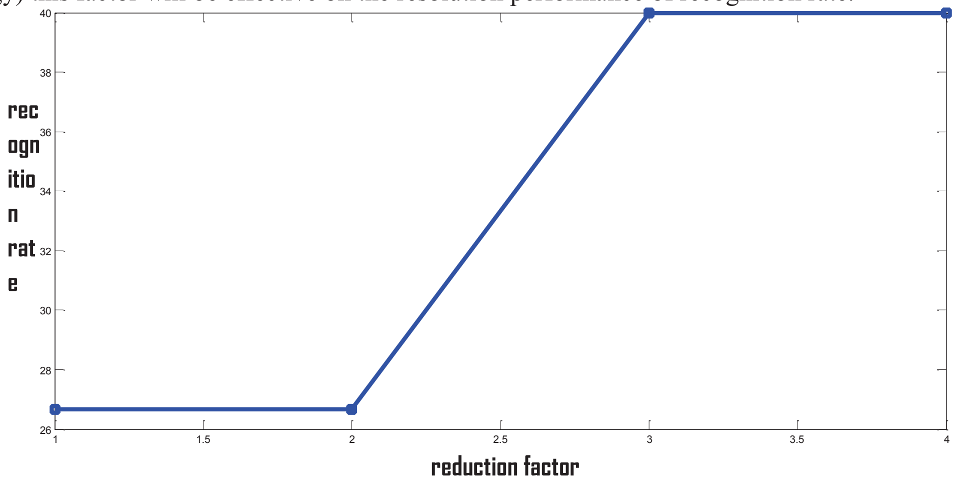

Figure 4.9 Experiments Results of Yale-Face Database Sample using Gaussian Pyramid

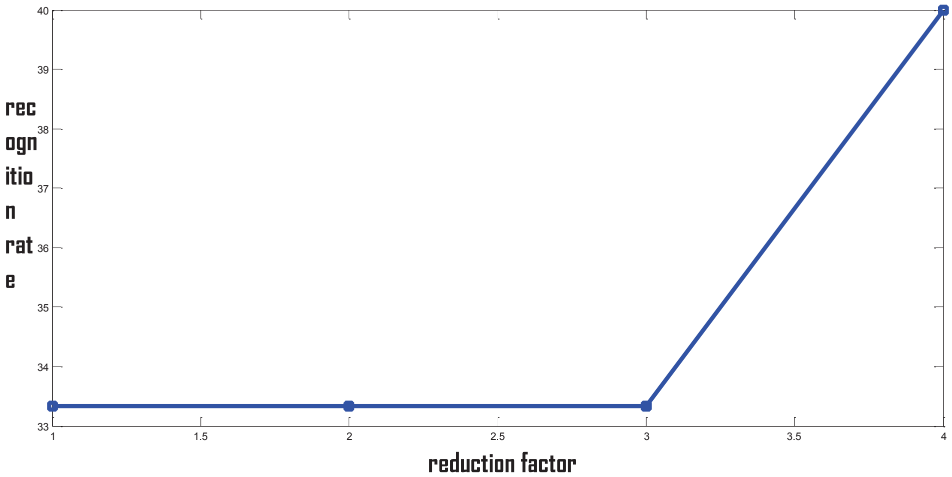

Figure 4.10 Using Bicubic Interpolation Algorithm on Yale-Face Database's Sample

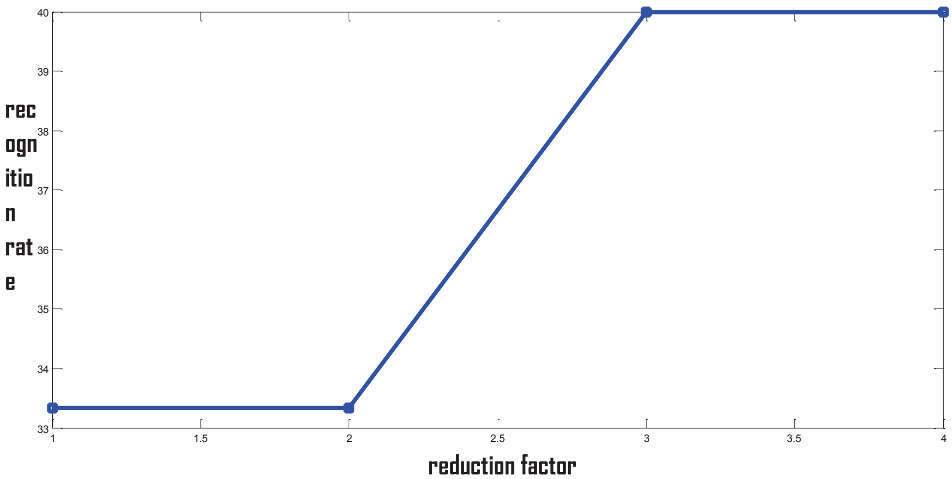

Figure 4.11 Using Nearest Neighbor Interpolation Algorithm on Yale-Face Database's Sample

The result is depicted in Figures 4.9, 4.10, and 4.11 from the curve changing trend, where the reduction rate match the required resolution that enable the system recognize the face, it can observe that the threshold recognition rate is moved suddenly at specific reduction rate, the rate keeps stable when the matched resolution reached.

In conclusion, the plots in Figures 4.6, 4.7, and 4.8 and Figures 4.9, 4.10, and 4.11 report the recognition performance as a function of recognition accuracies for different interpolation classifier. With each an interpolation algorithm, we reduce the high-images resolution three times using a reduction factor equal to ¼ applying on each successive image. In all experiments, the recognition rate shows an increasing trend when the reduction factor increase (reduce pixels of face images/high resolution faces).

3. Interpolation Method

The result is depicted in Figure 4.12 is stable trend, we can observe that the threshold recognition rate is stable with the increasing of reduction factor, the rate keeps stable when the reduction factor increases, which means the performance of image resolution recognition rate has been improved when I resize small image to get original size.

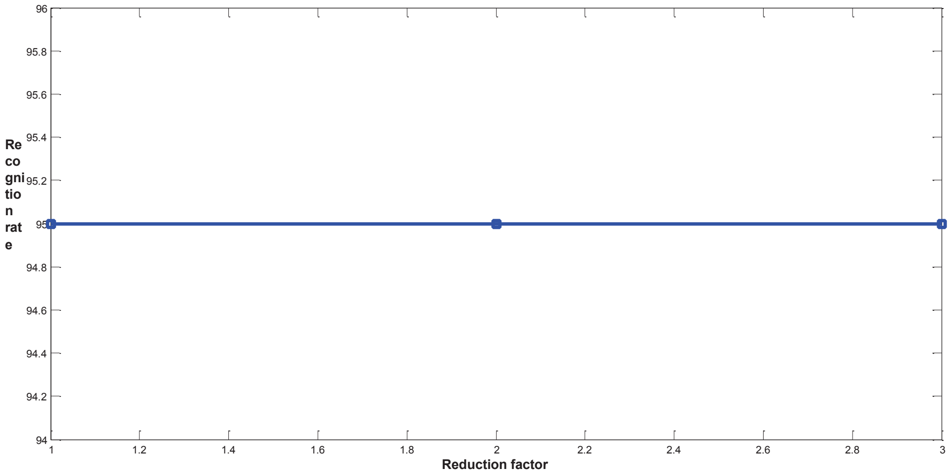

Figure 4.12 Effect of using interpolation on ORL-Face Database.

4. Super Resolution (SR) Method

By implementing the super resolution technique, it showed the same results shown above in the Figures 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12 based on Gaussian Pyramid, Bicubic, and Nearest Neighbor Interpolation Algorithms. (The results did not attach again to avoid the redundancy).

4.6 Conclusion

In this chapter, qualitative data obtained from the Images' Databases were analyzed. The images consisted of different times, varying lighting slightly, and facial expressions. Experiments showed that several issues related to image resolutions might have an impact on the recognition rate performance.

This exploratory work has revealed some interesting relationships among image resolution recognition methods, the findings must be considered in the context research study. To verify the results shown here, further study would require more rigorous methods of data collection and significantly greater sample size than included here.

CHAPTER 6: CONCLUSION AND FUTURE WORK

In this study, the relation between face recognition rate and face image resolution by classifying face image information into the discriminative and structure information. Then, The Eigen-Face algorithm uses the Principal Component Analysis (PCA) for dimensionality reduction to find the vectors which best account for the distribution of face images resolution within the entire image space. The experimental results presented in the experiment results section are obtained using the ORL-Face and Yale-Face B Database. In this experiment, I tested PCA face recognition method with: Gaussian Pyramid, Nearest Neighbor Interpolation, and Bicubic Interpolation Classifiers. The algorithm has been implemented using MATLAB.

In order to examine more carefully how image-based resolution face recognition system works, I did much extensive experiments with different sets of training images. Images are selected randomly based on different facial expressions, gender, race, and distance; 90 samples of ORL-Face database and 100 samples of Yale-Face Database B were selected randomly to train the system. 140 samples were used randomly as test images for testing, and 28 images for training. The noticeable fact is that the smaller the size of training set is, the more the reconstruction errors are. This is because there are more basis vectors (eigenvectors) to express the given data (faces) in the feature space.

The Eigen-face system to perform face recognition gave me the basic idea of PCA and more extensive knowledge about the logical process. Although the face recognition results were acceptable, the system only using Eigen-faces might not be applicable as a real system. It needs to be more robust and to have other discriminant features.

Based on the experiment results, this study should be considered as an exploratory study. For the ORL-Face database, the threshold recognition rate is increases roughly (radical improvement) with the increasing of reduction factor, the rate keeps stable when the high resolution reducing to reach a specific point of matching. For the Yale-Face B database, the threshold recognition rate is moved suddenly at specific reduction rate, the rate keeps stable when the matched resolution reached.

The study has steered me to many lessons being learned from the research conducted to investigate the used method for testing the image-based resolution for face recognition system, and the impacts of algorithms and the way of images selection used as well as the sample size. The study has improved my research and analytical skills, and extends my knowledge in the fields of biometrics system, evaluation of the face recognition system, the role of facial expressions, gender, race, and others. And it has involved me more in the applying research findings into practical work.

To verify the results shown here, further study would require more rigorous methods of data collection and significantly greater sample size than included here.

In the light of the results of the study, the research suggests the following recommendations for future work:

1) The images have to be processed for more accurate results by cropping the face images for excluding the background, Image cropping pre-process was not used in my experiments setup methodology. Images' backgrounds have a distinctly different color composition than faces which influence on the image resolution.
2) Customized images scaling and zooming techniques could help more identifying image-based resolution as elementary process for the face recognition systems.
3) Researchers should adopt a mathematical techniques and algorithms together for more accurate results, in order to allow researchers compare with a set of results.
4) More researches should be done about the most appropriate facial expressions and characteristics that the face recognition systems rely on.

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